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THE EFFECT OF VIBRATION ON PERFORMANCE WITH
ELECTRO-OPTICAL AIDS TO NIGHT VISION

by

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and

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9013D.04

Released by:

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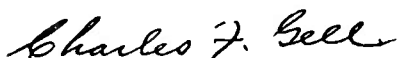
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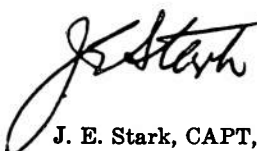
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SUMMARY PAGE

THE PROBLEM

To investigate the effect of ship's vibration on visual acuity using electro-optical aids to night vision.

FINDINGS

Low frequency vibration, with amplitudes comparable to those occurring aboard ship, caused marked decrements in the acuity of the operators of electro-optical aids. Comparison of the size of this decrement with that occurring for other optical systems, including the naked eye, revealed that the most severe losses were found for instruments that yielded the best acuity with no vibration. Despite the loss, vision with the four-power electro-optical aid remained superior to that with any other system.

APPLICATION

Electro-optical aids to night vision are being modified by the Navy to optimize performance at sea. This study is part of a larger investigation to determine the effect of typical Naval applications on the effectiveness of the devices.

ADMINISTRATIVE INFORMATION

This investigation was conducted under contract with the Navy Underwater Sound Laboratory and as part of Bureau of Medicine and Surgery Work Unit MF12.524.004-9013D. This report is No. 4 on that Work Unit. It was approved for publication on 18 July 1969 and designated as SubMedResLab Report No. 589.

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ABSTRACT

Visual acuity at a level of illumination comparable to overcast starlight was measured at various frequencies and amplitudes of vibration chosen to be representative of conditions aboard various ships. Measures were made with electro-optical scopes of four-power and one-power, standard Navy 7x50 binoculars, four-power field glasses, and the naked eye. Decrements in acuity under vibration were largest for the four-power scope and least for the naked eye; they were, in fact, directly related to the original acuity level determined for the specific optical systems with no vibration. Despite the loss, vision with the four-power electro-optical aid remained superior to that with any other system under all conditions. These results indicate the usefulness of the aids under Naval operating conditions and, additionally, emphasize the importance of anti-vibration mounts.

THE EFFECT OF VIBRATION ON PERFORMANCE WITH ELECTRO-OPTICAL AIDS TO NIGHT VISION

INTRODUCTION

Electro-optical aids to night vision, developed by and widely used in the Army, are being assessed and modified for Naval use.* These passive, direct view systems employ image-intensifier tubes which amplify the natural illumination by factors up to 100,000. Designed to improve the ability of human beings to see under conditions of inadequate illumination, as may be encountered at night, they operate most efficiently from 10^{-5} to 10^{-3} foot-candles; these levels cover the range of natural illuminations from approximately quarter moon to overcast starlight. One report comparing the effectiveness of the 10° Starlight Scope to that of 7x50 binoculars and unaided vision indicates that visual sighting-ranges from three to ten times that of the binoculars may be obtained with the scope.¹

The use of the aids aboard ship presents a problem not often encountered in Army operations—the effect of ship's vibration on their effectiveness. Vibration is known to adversely affect unaided visual acuity. Magnification of the image further increases the problem, the decrement in acuity with vibration being directly proportional to the amount of magnification. Thus, the effectiveness of hand-held binoculars is severely limited by simple hand-tremors; it has in fact been suggested that binoculars having a magnification greater than four-power be mounted in anti-oscillation fixtures, if any appreciable vibrations will occur in normal usage.²

A further difficulty arising from vibrations is specific to the electro-optical aids; that is, the image tubes are coated with a phosphor which has a measurable decay time. Vibration will cause the same image to activate different spatial locations on the phosphor resulting in blurred contours.

Ideally, one would hope to find data in the

literature relevant to the question of the effect of vibration on acuity. Indeed, the problem has been investigated many times over the years,³ but the number of crucial variables involved has precluded systematic study of each. For acuity, for example, the factors of illumination level, degree of contrast, retinal position, and type of target, must be considered as well as frequency and amplitude of vibration and the position of the subject. Understandably, the factors used in each investigation have been those of greatest concern to the sponsoring organization and have been relatively few in number. It is thus impossible to draw any generalizations from the available data to relate to a new problem—in this case what to expect from electro-optical aids to night vision. For example, all acuity studies have been done with sitting or supine subjects—we are interested in standing subjects. Illumination level has never been considered as a variable; investigators have used photopic levels exclusively—we are interested only in scotopic levels. The range of frequencies from 30 to 140 cps has been the major concern of the Air Force—vibration aboard ships is of interest at lower frequencies. The interaction between vibration and phosphor decay time has, of course, not been the subject of investigation. And finally, the measure in several studies has been the number of errors made in reading dials or letters. This measure is specific to the particular figures used in the specific viewing conditions employed; it is almost impossible to generalize from such data to other conditions. In short, there are no data pertinent to the topic from which predictions can be made.

This study, then, is an assessment of the effect of vibration upon the effectiveness of electro-optical aids at night. Since the primary concern is for Naval use, frequencies and amplitudes of vibration were selected to be representative of conditions found aboard Naval ships.

Data on various types of ship vibration have been summarized and analyzed by Buch-

*The Naval Underwater Sound Laboratory has been assigned the task of modifying these instruments for Naval use. This report was written under contract (WR-8-0023) with USN/USL.

man.⁴ His measures show that for machinery and propeller-excited vibrations, there is a rapid rise in acceleration from 4 to 10 cps and a nearly constant level of acceleration at higher frequencies. We arbitrarily chose one low frequency, 5 cps, and one located on the acceleration asymptote, 20 cps, for study.

Table I gives some sample values for 5 and 20 cps from Buchman's report for two extreme conditions on two types of ships. Measures were made on the fantail and thus represent the worst possible condition. Accelerations vary markedly with the frequency, the sea state, and the type of ship. The low frequency component is larger for carriers than for destroyers while the reverse is true for the high frequency component.

TABLE I

Acceleration magnitudes, in g's, for extreme vibration levels,* at the two frequencies selected for study (from Buchman⁴).

	Vibration Level I		Vibration Level IV	
	Destroyer	Carrier	Destroyer	Carrier
5 cps	.01	.04	.02	.08
20 cps	.4	.2	.8	.4

*Vibration levels are mathematically defined in Buchman's report as a function of the ship's length and the sea state. For the purposes of this report, they may be thought of as effective sea states from calm (I) to rough (IV).

Accelerations of .02 and .04 at 5 cps and of .2 and .4 at 20 cps were selected as representative of ship's vibration. They occur commonly on both types of ships. Higher values will be encountered, but presumably only on the fantail.

The acuity measure selected was the standard square-wave grating target composed of equal width, black and white stripes. Data collected with this target are thus directly comparable to many classical acuity studies and to the newer modulation transfer functions.⁵ Measures were made with two different electro-optical aids and with various other optical systems, so that the amount of decrement could be assessed against standard viewing systems.

APPARATUS AND PROCEDURE

A series of 30 square wave gratings or grid targets were provided in black and white of nearly 100% contrast. The widths of the grid lines varied from 2.73 inches to .114 inches. Each target consisted of six black and five white bars of equal size; consequently, as the bar lines decreased in width, the overall extent of the target decreased in direct proportion.

At the observing distance of 40 ft., the width of the bars subtended visual angles ranging from 1 to 20 minutes in size. This range can also be specified as 1 to .05 lines/min. of arc or 30 to 1.5 cycles/degree.

The targets were illuminated by a low intensity light source approximating the spectral distribution of starlight. The source was positioned to yield a luminance of 10^{-4} ft-L, reflected from the white portion of the targets. Measures were made with the Spectra Pritchard Photometer. This specific luminance level was selected to be typical of nighttime operations since it is (1) intermediate to luminances found on cloudy and moonlight nights, and (2) in the middle of the range of maximum effectiveness of the scopes.¹

The method of constant stimuli was used to obtain thresholds for the various experimental conditions. Subjects were instructed to respond "Horizontal" or "Vertical", depending upon the position of the stripes, or "No" if they could not see them.

The range of useful targets was first determined by a method of limits. Three specific sizes were selected and presented, in random order, five times each, in each of the horizontal and vertical positions. Thus, the 50% thresholds were each based upon 30 judgments.

Subjects focused each of the devices from a stationary position before starting the actual measures. They were informed about peripheral viewing and told to try looking off-center to see if it helped them resolve the target. They were periodically reminded that peripheral vision might be required with some of the devices.

Vertical, sinusoidal vibrations were provided by a mechanical shake-table. Two am-

plitudes at each of two frequencies were investigated: .02 and .03 inch double amplitude at 5 cps, and .01 and .02 at 20 cps. These amplitudes yield acceleration values of .025 and .0375 g for 5 cps and .2 and .4 g for 20 cps.

Subjects stood on the shake-table and were told to make themselves as comfortable as possible. The shake-table was fitted with pipe railings comparable to those found aboard ship. Thus, the subjects could brace themselves or hold on to the railing if they wished.

Four different optical devices were used: one-power and four-power electro-optical aids, standard 7x50 Navy binoculars and four-power field glasses. Unaided acuity was also measured as a control. Each of these five visual systems was employed under each of the four vibration conditions and under a no-vibration condition. The order of presentation of the various combinations was randomized.

A complete set of acuity measures was obtained on each of four subjects. Two of the subjects were emmetropic; one subject was myopic, but wore contact lenses throughout; the fourth was hyperopic, but corrected to 20/20 with either glasses or the focusing adjustments of the various visual systems.

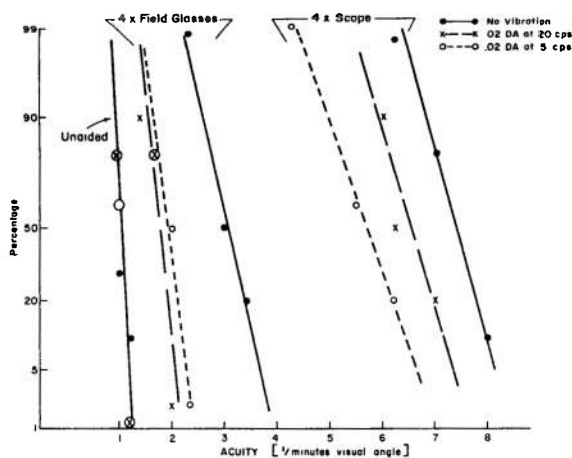


Fig. 1. Sample data for one subject to show the method of obtaining the acuity limens.

RESULTS

Sample data for one subject are shown in Fig. 1 to illustrate the method of obtaining the acuity limens. The percentage of the stimuli which resulted in correct reports of the orientation of the grid is plotted as a function of acuity. Since acuity is the reciprocal of minutes of arc subtended by a stripe, it is equivalent to lines/min. of arc (30 cycles/degree). Thus, stripe widths vary from approximately 10 min. of arc at the left side of the figure, to .125 min. at the right. The 50% limens, determined for each of the functions, are given in Table II for each subject.**

The average limens for the four subjects are shown in Fig. 2. A comparison of the acuity obtained with the different optical devices reveals large differences. Unaided acuity is, of course, poorest, averaging about one-seventh of that for the best system, the four-power scope. Standard Navy 7x50 binoculars result in significantly better acuity than either the one-power scope or the four-power field glasses.

The effect of vibration on acuity varies with the specific optical system employed. Unaided acuity is the same for all conditions, while acuity using the 7x50 binoculars or the four-power scope is considerably reduced under vibration. The one-power scope and the four-power field glasses show intermediate effects. Under the conditions of this experiment, the decrements are never so great that the relative rank of the optical devices is changed. Thus, acuity through the four-power scope remains superior to that with all

**These data represent the physical size of the targets used and not the optical size. Some of the optical systems, of course, magnify the image and the limens could be specified in terms of this measure. However, performance with optical systems rarely achieves the theoretical maximum predicted by simple magnification, so it is preferable to specify the physical characteristics. For example, the average limen with four-power field glasses was 3.9 min; the optical size is thus 3.9×4 or 15.6 minutes. Similarly, the average limen for the 7x50 binoculars was 2.2 min yielding an optical size of 15.4. Both of these are larger than the unaided average of 10 minutes, showing a loss from the level predicted by the magnified optical image.

other systems, despite the fact that sizeable losses occur with vibration.

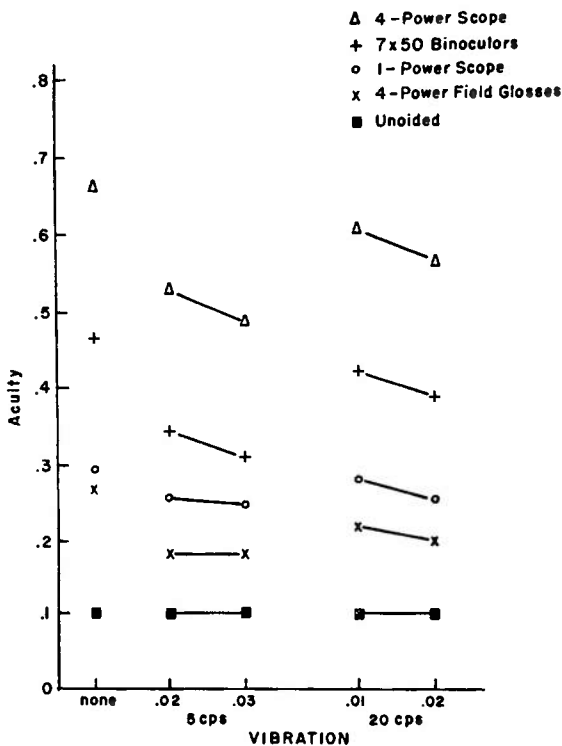


Fig. 2. Average acuity under the different conditions of vibration for the various optical systems.

An analysis of the amount of decrement suffered with vibration for each of the systems is depicted in Fig. 3.[#] Unaided vision shows no loss, and the one-power scope suffers very little with vibration. Largest losses are evidenced for the four-power scope and the 7x50 binoculars. The higher-powered instruments are hindered more by the low-frequency vibration than the high. A comparison of the two systems that share the same magnification reveals that performance with the scope suffers a greater handicap with vibration than does performance with the field glasses.

[#]Loss of acuity is defined as acuity under vibration conditions subtracted from that under no vibration for the same optical system. The simple subtraction is appropriate since acuity ($\frac{1}{\text{mins. visual angle}}$) is linearly related to many physical variables.

The losses depicted in Fig. 3 represent an overall or average decrement. The decrement, however, was often much more severe in the horizontal dimension than in the vertical. Thus, a generalized acuity difference of .15 may represent a loss of .25 units when the bars are horizontal and .05 when they are vertical. An analysis of the horizontal and vertical data, separately, revealed that small losses, of .05 or less, were interspersed equally in the two dimensions. Larger decrements, however, were always much more severe for targets whose stripes were placed at right angles to the vibratory motion.

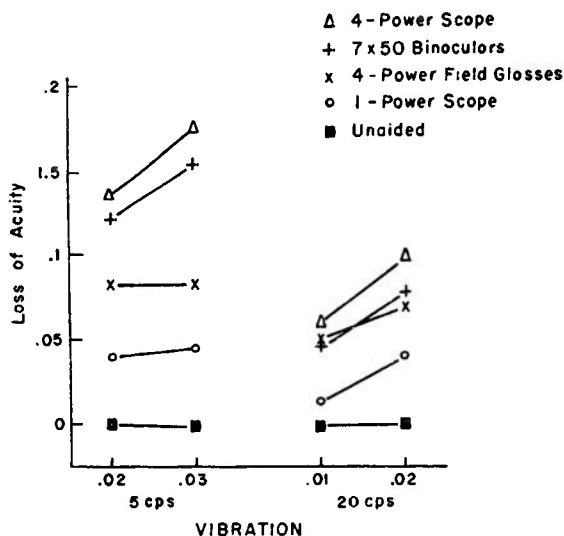


Fig. 3. Average loss of acuity under the various vibration conditions.

The same analysis of the loss of acuity with vibration is portrayed for the individual subjects in Fig. 4, to illustrate the magnitude of individual differences. In general, all subjects behave similarly under all experimental conditions. Thus, none shows any decrement using unaided vision and the amount for the one-power scope is minor for everyone. On the other hand, use of the 7x50 binoculars and the four-power scope is considerably impaired by vibration, particularly at the 5 cps condition. The rank order of the instruments by amount of decrement is essentially the same for all subjects.

There are, however, two marked cases of individual differences in performance pat-

terns. Using the four-power scope, two of the subjects suffered a much greater loss at 5 cps than at 20 cps, while the decrement for the other two was fairly constant across all

or could not be perceived under various field conditions.

The acuities in this study may be viewed by this method of analysis. Thus, an object

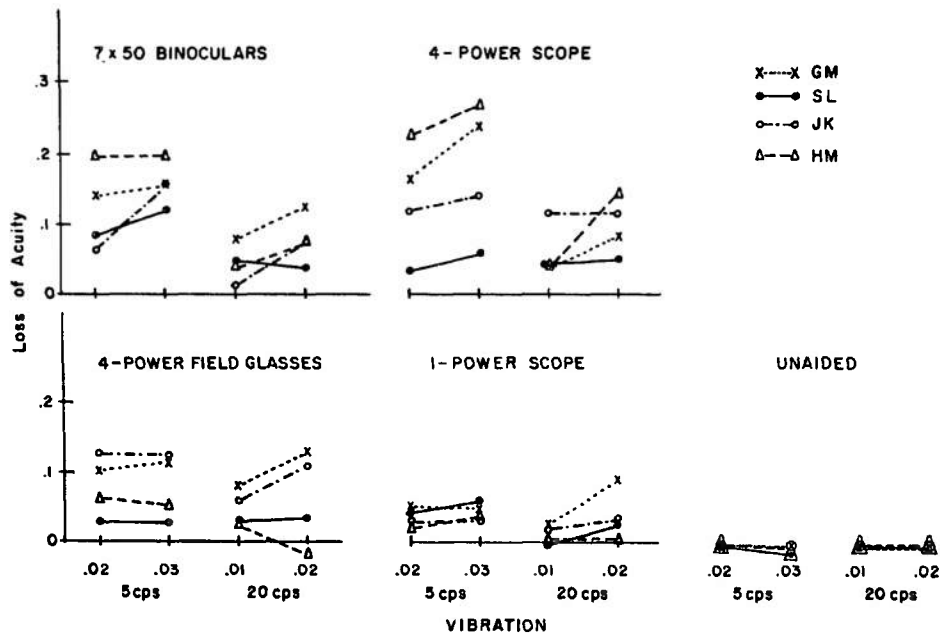


Fig. 4. The loss of acuity suffered by each individual for all conditions.

vibration conditions. Similarly, there were differences in performance with the four-power field glasses: two of the subjects had a sizeable loss under each vibration condition, while the other showed very little, the magnitude being comparable to that with the one-power scope. Inspection of the absolute acuity levels of the subjects (Table II) reveals that the subjects who had the best acuity under the no-vibration conditions were the same ones in each case whose performance was the most handicapped by vibration. This is true even if the data are normalized; that is, the loss is divided by the individual's acuity under no vibration to equate for individual differences.

DISCUSSION

There are two different methods of assessing the amount of decrement in acuity suffered under various experimental conditions. One employs a ratio of the sizes of targets resolved, or specifies loss in terms of a percentage value. Such an analysis is certainly operationally meaningful since it can be used to yield predictions of target sizes that could

TABLE II
Visual Acuity for Individual Subjects
(1/minutes of visual angle)

S	Vibration Freq. DA	Optical Systems				
		Un-aided	4X Field Glasses	7X50 Binoculars	1X Scope	4X Scope
GM	None	.103	.305	.520	.357	.735
	5 cps .02	.103	.200	.380	.305	.570
	.03	.103	.190	.365	.305	.496
	20 cps .01	.103	.223	.440	.328	.698
	.02	.103	.173	.395	.265	.650
SL	None	.095	.200	.420	.322	.620
	5 cps .02	.095	.170	.335	.277	.585
	.03	.100	.170	.300	.262	.560
	20 cps .01	.095	.170	.370	.325	.575
	.02	.095	.164	.380	.295	.570
JK	None	.114	.340	.415	.210	.528
	5 cps .02	.114	.212	.350	.180	.410
	.03	.114	.214	.265	.175	.387
	20 cps .01	.114	.280	.400	.185	.412
	.02	.114	.230	.340	.175	.412
HM	None	.085	.225	.510	.292	.770
	5 cps .02	.085	.160	.315	.268	.546
	.03	.090	.170	.315	.256	.505
	20 cps .01	.090	.200	.470	.285	.728
	.02	.085	.240	.435	.285	.628

must be $6\frac{2}{3}$ times as large to be seen by the naked eye as with the four-power scope at 10^{-4} ft-L. In operational terms, this means that a ship could be identified at seven times the distance with the scope, if the effects of atmospheric attenuation are ignored. Similarly, if a target can be seen with 7x50 binoculars without vibration, it will require an increase in size of 50% to be identified under vibration conditions of 5 cps at a double amplitude of .03 inches.

The second type of analysis, already presented for these data, describes the loss by subtracting the visual acuities for vibration from those found under stationary conditions. The rationale for this analysis stems from the fact that the visual system does not operate in a linear manner with respect to units of size. Or, in other words, a 50% increase in size for a 10-minute target is not as important or as meaningful a visual loss as a 50% increase for a 2-minute target. Rather the

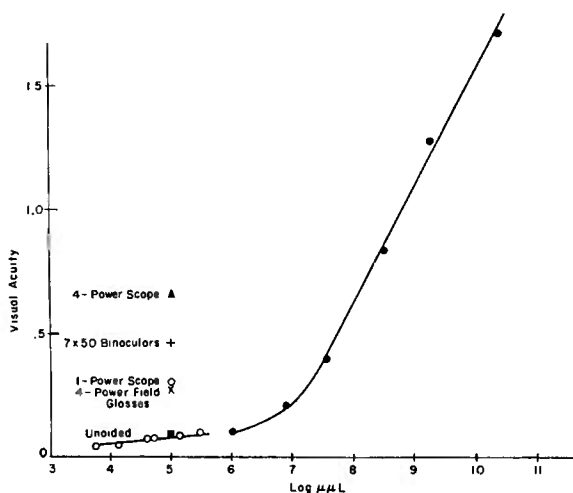


Fig. 5. The general relationship between visual acuity and level of illumination for unaided acuity. Acuities obtained in this study for each of the optical systems under the no vibration condition have been plotted on this general curve.

reciprocal of size (visual acuity, lines/min. or cycles/degree) is the measure that is linearly related to many environmental variables.

One such functional relationship, that between visual acuity and illumination level, is

of primary importance in comparing the effectiveness of various visual systems at night. Figure 5 shows for unaided vision this relationship with illuminations from 10^{-6} to 10^2 ft-L plotted on the abscissa. The data from this experiment, all of which were collected at an illumination level of $5 \log \mu\mu\text{L}$ (10^{-4} ft-L) show the acuities which resulted with the various optical devices. Unaided acuity is, of course, exceedingly poor; the value of .1 (10 min. visual angle) falls on the typical scotopic branch of the unaided acuity function. Showing a tremendous advantage over the unaided eye, 7x50 binoculars yield an acuity of .46. Interpolation of these figures into the acuity-luminance relationship pictured reveals that the light level would have to be increased to $7.6 \log \mu\mu\text{L}$ (or by a factor of 240 times) to achieve the same discrimination with the naked eye.

Acuity realized with the four-power scope is even more impressive. In order to reach the level of .65, the naked eye would require approximately $8 \log \mu\mu\text{L}$,—an intensity well into the photopic range.

The loss of acuity suffered under vibration may also be analyzed with reference to Fig. 5. The loss of acuity of .176 suffered by the four-power scope under vibration is comparable to a loss of illumination of .4 log unit, or would require $2\frac{1}{2}$ times as much additional illumination to compensate for it. Smaller losses in acuity are, of course, comparable to smaller illumination losses since the relation between acuity and illumination level is a linear one.

By this method of analysis, the performance with the four-power scope is hindered more by vibration than that with any of the other instruments. The second largest decrement is found with the 7x50 binoculars, and the least with the one-power scope and the naked eye.

There are a number of possible reasons for the larger decrements. Of obvious importance is the magnification of the optical system. While it is generally true that the higher powered instruments are the only ones to show an acuity loss, it is also obvious that other factors must be involved. Thus, the

two instruments that share a common magnification factor show very different losses; furthermore, the 7x50 binoculars show less decrement than the four-power scope.

More pertinent, perhaps, than the amount of magnification per se, is the amount of magnification relative to the target size to be detected.

Under the extreme assumption that all of the vibration from the shake-table is delivered to the head, one can calculate the amplitudes imparted to the eye through the various optical systems.⁺ These vary from a few seconds of arc, for a system with no magnification, to over a minute, for the 7x50 binoculars. These amplitudes are insignificant compared to a 10 min. target required for unaided vision at this light level. On the other hand, resolution is in the one to three minute range for both the four-power scope and the 7x50 binoculars; here deviations of a minute become meaningful.

It appears then that a major consideration is the level of acuity achieved with a given system—the better the acuity, the more likely a sizeable decrement will occur. This assumption fits not only with the rank order of relative effectiveness of the instruments, but also with the performances of individuals on the same instruments. Thus, if an individual, for one reason or another, performs exceptionally well with a specific device, his acuity loss with vibration will be greatest.

⁺It is, of course, unreasonable to assume that 100% of the vibration is transmitted to the head of a standing subject. Transmissibility of vibration (the ratio of accelerations measured at various parts of the body to that applied by the shake-table) varies with the frequency. For seated Ss it is characteristically high around 5 cps, sometimes exceeding 100%, but may drop to 20-50% at higher frequencies.⁶ Furthermore, under our experimental conditions, in which the subject remained on the shake-table for 15 to 30 minutes at a time, it can be predicted that the percentage for all frequencies is high. In a study of the effectiveness of the human leg in damping low-frequency vibrations, Hornick⁷ has shown that legs rapidly lose their effectiveness. In the brief time period of 2 min. exposure, the accelerations at the head rose from 68 to 93% for 2 cps and from 25 to 39% for 5 cps.

One test of this assumption is to compare acuity losses for the magnification of the optical systems evaluated according to the acuity achieved with each under no vibration. This has been done in Fig. 6; the correlation coefficient for these data is .88. Thus, there is excellent support for the statement that a major source of the acuity loss under vibration is the angular motion of the instrument, increasing too much with respect to size of the target that can be resolved.

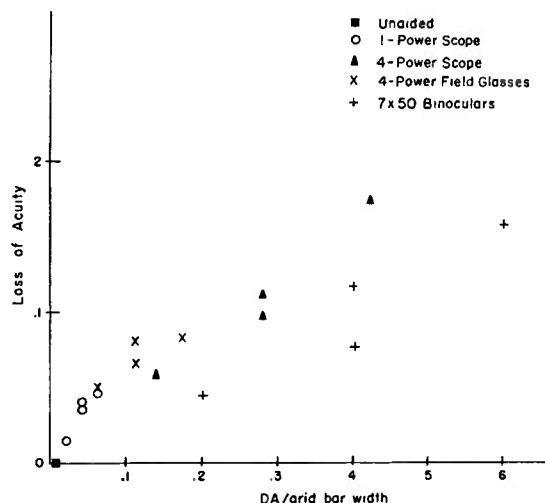


Fig. 6. The relationship between loss of acuity and amplitude of vibration compared to target size that can be resolved with no vibration.

A similar analysis has been made by Bossler for vibrating grids and a stationary subject; no magnification systems were employed. Bossler states that, "It was expected that peak-to-peak motion equal to the width of a black bar would cause blurring at high frequencies. However, as shown in Fig. 1, in about 50% of the observations the tolerable motion, i.e., unblurred, was about 1.3 black bar widths, while in about 1% of the cases, the observer reported blurring with a peak-to-peak motion of only 0.3 black bar widths."⁸

Decrements have been shown in this study for black bar widths of much lesser magnitude. Our measure, 50% threshold for resolution, is undoubtedly more sensitive than that of Bossler which consisted of increasing

the amplitude until the subject reported blurring. Other factors, too, could be expected to increase the decrement observed in this study. Natural damping of the vibration by various parts of the body is more difficult for the heavier devices. Blurring of the image on the tube will be caused by the lengthy decay time of the phosphor, which can consume several seconds. And, finally, it is possible that more decrement occurs for a stationary target and moving subject than the reverse.

While acuity with the four-power scope showed the greatest decrement with vibration, it remained superior to that of the other devices under all experimental conditions. At some point, however, the decrement could be of sufficient magnitude that the rank order of the instruments would change; that is, the one-power scope or the naked eye would yield better vision. Vibration amplitudes in excess of those used in this study do occur on ships. For example, at 20 cps, .4 g (.02 DA) is unusually severe for carriers, occurring less than .5% of the time; on destroyers, .4 g is extremely moderate; higher g's (up to .8) occurring 89% of the time. The occurrence of higher amplitudes than .04 for the 5 cps condition is just the reverse—very infrequent in destroyers and common on carriers.⁵ Thus, it is expected that amplitudes at least double those used here will be encountered at sea. Unaided acuity cannot be expected to deteriorate under these conditions: the target sizes required for resolution are too gross compared with the maximum amplitude of vibration. Even at high illumination levels, where target resolution is vastly superior, little loss of unaided acuity has been reported at these amplitudes.³

The higher powered instruments, on the other hand, will certainly suffer more decrement, probably at an increasing rate as amplitude is increased. The unfortunate conclusion is that a great deal of the advantage inherent in the use of electro-optical aids may be lost under severe conditions. In the development of aids for the Navy, strong emphasis should be placed on anti-vibration mounts.

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TO NIGHT VISION

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13. ABSTRACT

Visual acuity at a level of illumination comparable to overcast starlight was measured at various frequencies and amplitudes of vibration chosen to be representative of conditions aboard various ships. Measures were made with electro-optical scopes of four-power and one-power, standard Navy 7x50 binoculars, four-power field glasses, and the naked eye. Decrements in acuity under vibration were largest for the four-power scope and least for the naked eye; they were, in fact, directly related to the original acuity level determined for the specific optical systems with no vibration. Despite the loss, vision with the four-power electro-optical aid remained superior to that with any other system under all conditions. These results indicate the usefulness of the aids under Naval operating conditions and, additionally, emphasize the importance of anti-vibration mounts.

14.

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